Editorial: Fourth Quarter 2015 IEEE Communications Surveys and Tutorials

I WELCOME you to the fourth issue of IEEE COMMUNICATIONS SURVEYS AND TUTORIAL (ComST) in 2015. This issue includes 25 papers covering different aspects of communication networks. In particular, these papers cover various issues in wireless communications and networks, Internet, data networks and security, and vehicular and sensor networks. A brief account for each of these papers is given below.

I. WIRELESS COMMUNICATIONS AND NETWORKS

An error-correction coding system adds redundant data or parity data to a message such that the message can be recovered by a receiver when errors are introduced either during the process of transmission or on storage. In this context, extrinsic information transfer (EXIT) chart is a technique that can be used for the construction of good iteratively decodable error-correcting codes [in particular, low-density parity-check (LDPC) codes and turbo codes] for a variety of communication systems. The paper titled "Near-Capacity Wireless System Design Principles" by Hung Viet Nguyen, Chao Xu, Soon Xin Ng, and Lajos Hanzo presents a tutorial on the design procedure of near capacity channel code invoking nonbinary EXIT charts. It illustrates the design procedure by using design examples of irregular concatenated coding arrangements (ICCAs) relying on irregular convolutional codes (IrCCs). In addition, the EXIT-chart aided near-capacity design principles are illustrated by detailing the design process of three characteristic prototype schemes, which represent the family of coherent and noncoherent detection-based systems as well as multi-input multi-output (MIMO) systems, respectively. Moreover, the beneficial application of the EXIT-chart-based design principle is also demonstrated in the context of co-operative systems using a specific distributed MIMO prototype scheme. Finally, the paper highlights some possible future research directions.

A cognitive radio (CR) is an intelligent radio that can be programmed and configured dynamically. A CR transceiver is designed to use the best available wireless channel(s). Such a radio automatically detects the available channels and accordingly changes its transmission or reception parameters to achieve efficient wireless communications in a given spectrum band. Power control and beamforming are two key techniques in CR design, which can be used to maximize the benefits of CR users. However, the available system parameters (e.g., channel state information and interference power) to enable power control and beamforming could be uncertain due to various factors such as estimation error and/or measurement error. In this context, the paper titled "Robust Power Control and Beamforming in Cognitive Radio Networks: A Survey" by Yongjun Xu, Xiaohui Zhao, and Ying-Chang Liang presents a survey on robust design for power control and beamforming in CR networks. The paper describes the modeling methods for parametric uncertainties, introduces various design methodologies, and presents robust algorithms available in the literature. Finally, the paper outlines some potential issues and future research directions in this field.

In the same context of CR networks, the paper titled "Cognitive Radio Techniques Under Practical Imperfections: A Survey" by Shree Krishna Sharma, Tadilo Endeshaw Bogale, Symeon Chatzinotas, Bjorn Ottersten, Long Bao Le, and Xianbin Wang presents another survey. The paper provides an overview of the enabling techniques for CR communications. Subsequently, it discusses the main imperfections that may occur in the most widely used CR paradigms and then reviews the existing approaches toward addressing these imperfections. Finally, it provides some interesting open research issues.

As telecom operators are struggling to accommodate the existing demand of mobile users, new data intensive applications and services (e.g., proximity-aware services) are emerging. Therefore, researchers are seeking for new paradigms to revolutionize the traditional communication methods of cellular networks. Device-to-device (D2D) communication is one of such paradigms and a promising component of next generation cellular technologies. D2D communication in cellular networks is defined as direct communication between two mobile users or devices without having the base station (BS) as an intermediate node. D2D communication is generally nontransparent to the cellular network and it can occur on the cellular spectrum (i.e., in-band) or unlicensed spectrum (i.e., out-of-band). In this context, the paper titled "In-Band Device-to-Device Communication in OFDMA Cellular Networks: A Survey and Challenges" by Pavel Mach, Zdenek Becvar, and Tomas Vanek presents a comprehensive overview of the state-of-the-art of D2D communication, especially within 3GPP LTE/LTE-A. The paper starts by providing an in-depth classification of papers looking at D2D from several perspectives. Then, it surveys other papers addressing all major problems and areas related to D2D. Then, the paper highlights some research directions that are worth further investigation.

In the same context of D2D communications, the paper titled "Device-to-Device Communication in LTE-Advanced Networks: A Survey" by Jiajia Liu, Nei Kato, Jianfeng Ma, and Naoto Kadowaki presents a comprehensive survey of available D2D-related research works ranging from technical papers to experimental prototypes to standard activities, and outlines some open research problems which deserve further studies.

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Very large MIMO system is a new research field both in communication theory, propagation, and electronics. The ultimate vision of very large MIMO systems is that the antenna array would consist of small active antenna units, plugged into an (optical) fieldbus. With very large MIMO, systems will use antenna arrays with an order of magnitude more elements than in systems being built today, say 100 antennas or more. Very large MIMO entails an unprecedented number of antennas simultaneously serving a much smaller number of terminals. The disparity in number emerges as a desirable operating condition and a practical one as well. The paper titled "Fifty Years of MIMO Detection: The Road to Large-Scale MIMOs" by Shaoshi Yang and Lajos Hanzo presents a survey on novel challenges facing large-scale (LS)-MIMOs from a detection perspective. More specifically, the paper highlights the fundamentals of MIMO detection, including the nature of cochannel interference (CCI), the generality of the MIMO detection problem, the received signal models of both linear memory-less MIMO channels, and dispersive MIMO channels exhibiting memory, as well as the complex valued versus real-valued MIMO system models. Then, the paper provides an extensive review of the representative MIMO-detection methods conceived during the past 50 years. The paper discusses the relevant insights as well as lessons learnt in the context of designing complexity-scalable MIMO-detection algorithms that are potentially applicable to LS-MIMO systems. Finally, the paper discusses the applicability of existing MIMO-detection algorithms in LS-MIMO systems, and reviews some of the recent advances in LS-MIMO detection.

In information theory, an LDPC code is a linear error-correcting code that can be used to transmit messages over a noisy transmission channel. LDPC codes are capacity-approaching codes. This means that practical constructions exist that allow the noise threshold (upper bound for the channel noise up to which the probability of information loss can be made as small as desired) to be set very close to the theoretical maximum (the Shannon limit) for a symmetric memory-less channel. Using iterative belief propagation techniques, LDPC codes can be decoded in time linear to their block lengths. In this context, the paper titled "A Survey on Protograph LDPC Codes and Their Applications" by Yi Fang, Guoan Bi, Yong Liang Guan, and Francis C. M. Lau presents a survey on the state-of-the-art in protograph LDPC code design and analysis for different channel conditions, including the additive white Gaussian noise (AWGN) channels, fading channels, partial response (PR) channels, and Poisson pulse-position modulation (PPM) channels. Moreover, the paper studies applications of protograph LDPC codes to joint source-and-channel coding (JSCC) and joint channel-and-physical-layer network coding (JCPNC). Finally, the paper highlights possible future research directions.

The wireless revolution has resulted in ever-increasing demands on the limited wireless spectrum driving the quest for systems with higher spectral efficiency. Among the various ways to increase spectral efficiency, in-band full-duplex (IBFD) operation has recently gained much attention. The main idea behind IBFD is as follows. Most contemporary communication systems contain terminals (e.g., BSs, relays, or mobiles) that function as both transmitters and receivers. Conventionally, these terminals operate in half-duplex (HD) or out-of-band full-duplex, meaning that they transmit and receive either at different times, or over different frequency bands. Enabling wireless terminals to transmit and receive simultaneously over the same frequency band (i.e., IBFD operation) offers the potential to double their spectral efficiency, as measured by the number of information bits reliably communicated per second per Hz. Therefore, this is of great interest for next-generation wireless networks. The paper titled "A Survey of In-Band Full-duplex Transmission: From the Perspective of PHY and MAC Layers" by Dongkyu Kim, Haesoon Lee, and Daesik Hong presents a survey that covers a wide array of technologies that have been proposed in the literature as feasible for IBFD transmissions. It evaluates the performance of IBFD systems compared to conventional HD transmission from theoretical aspects such as the achievable sum rate, network capacity, and system reliability. The paper also discusses the research challenges and opportunities associated with the design and analysis of IBFD systems in a variety of network topologies. This work also explores the development of medium access control (MAC) protocols for IBFD systems in both infrastructure-based and *ad hoc* networks. Finally, the paper discusses the advantages of IBFD transmissions in applications such as spectrum sensing, network secrecy, and wireless power transfer.

Visible light communication (VLC) is an emerging field in optical wireless communication (OWC), which utilizes light-emitting diodes (LEDs) to transmit data. In modern communication systems, the most popular frequency band is radio frequency (RF) band. However, the rapidly dwindling RF spectrum along with increasing wireless network traffic has substantiated the need for greater bandwidth and spectral relief. By combining illumination and communication, VLC provides ubiquitous communication while addressing the shortfalls and limitations of RF communication. The paper titled "Visible Light Communication, Networking, and Sensing: A Survey, Potential and Challenges" by Parth H. Pathak, Xiaotao Feng, Pengfei Hu, and Prasant Mohapatra presents a detailed survey of VLC systems and characteristics of its different components (e.g., transmitter and receiver). Moreover, it overviews the physical layer properties of VLC channel, modulation methods and MIMO techniques, medium access techniques, system design and programmable platforms, and visible light sensing and application such as indoor localization, gesture recognition, screen-camera communication, and vehicular networking. Finally, the paper outlines important challenges that need to be addressed to design high-speed mobile networks using VLC.

A small cell is a low-power low-cost radio BS whose primary design objective is to provide superior cellular coverage in residential, enterprise, or hot spot outdoor environments. In general, radio coverage of small cell BSs can range from tens of meters to a few hundred meters. In small cells, due to shorter distances between the transmitter–receiver pairs, the transmit power required to achieve the same quality-of-service (QoS) scales down significantly. This transmit power reduction bodes favorably for power requirements of related BS hardware components, and the overall BS power drawn from the socket recedes. Faced with the exponential increase in data traffic,

the cellular network operators are confronted with a precarious situation: accommodate the ever-increasing traffic growth, yet reduce the costs and consequently increase average revenue per user. In this context, small cells are expected to play a big role. The paper titled "Towards 1 Gbps/UE in Cellular Systems: Understanding Ultra-Dense Small Cell Deployments" by David López-Pérez, Ming Ding, Holger Claussen, and Amir H. Jafari presents a survey on the recent advances toward ultra-dense small cell deployments. The paper starts by giving an overview on small cells in heterogeneous networks (HetNets) and how they need to be modified to meet future capacity demands. The paper then outlines different methods for network densification. Then, it overviews other techniques for boosting network throughput and assesses their performance. Finally, the paper outlines some future research challenges that require further investigation.

Game theory is a discipline used to model situations in which decision makers have mutual, possibly conflicting interests. Although originally developed in the field of economics, in the past several years, it has also been applied to wireless networking design. Some of the competitive environments in wireless networks lend themselves naturally to game theoretic formulations. One type of games is "repeated games". The paper titled "Applications of Repeated Games in Wireless Networks: A Survey" by Dinh Thai Hoang, Xiao Lu, Dusit Niyato, Ping Wang, Dong In Kim, and Zhu Han presents a survey on the applications of repeated games in different wireless networks. Furthermore, various problems in wireless networks and variations of repeated game models together with the corresponding solutions are discussed. Finally, some open issues and future research directions are outlined.

Space division multiplexing (SDM) using multicore fibers (MCFs) has been recognized as a key technology to extend the physical limit of transmission capacity of optical fibers. Increased attention has been paid to SDM and MCFs as the data rate of conventional fiber transmission is reaching its estimated limits and is unlikely to be able to accommodate the expected rise in the traffic demand in fiber optic networks in the coming decades. In this context, the paper titled "Survey and Evaluation of Space Division Multiplexing: From Technologies to Optical Networks" by George M. Saridis, Dimitris Alexandropoulos, Georgios Zervas, and Dimitra Simeonidou presents a survey on the research progress on SDM fibers and network components. It introduces two figures-of-merit (FoM) for quantitative evaluation of technologies such as amplifiers, fan-in/fan-out multiplexers, transmitters, switches, and SDM nodes. Moreover, the paper provides an analysis of crosstalk in MCFs and shows how SDM concepts can be exploited further to fit in various optical networks. Finally, research challenges and future directions are discussed.

II. Internet, Data Networks, and Security

Multipath routing techniques use multiple alternative paths through a network. These techniques can yield a variety of benefits such as fault tolerance, increased bandwidth, and improved security. The multiple paths computed might be overlapped, edge-disjointed or node-disjointed with each other. Extensive research has been done on multipath routing techniques. In this context, the paper titled "A Survey on Internet Multipath Routing and Provisioning" by Sandeep Kumar Singh, Tamal Das, and Admela Jukan presents a survey. It starts by outlining the benefits and basics of multipath routing components in the Internet. The paper then reviews various multipath protocols from application to link and physical layers. In addition, the paper describes the mathematical foundations of multipath operation and highlights the issues and challenges pertaining to reliable data delivery, buffering, and security in deploying multipath provisioning in the Internet. Finally, the paper compares the benefits and drawbacks of these protocols operating at different Internet layers and discusses open issues and challenges.

In the same context of multipath routing, the paper titled "Exploiting the Power of Multiplicity: A Holistic Survey of Network-Layer Multipath" by Junaid Qadir, Anwaar Ali, Kok-Lim Alvin Yau, Arjuna Sathiaseelan, and Jon Crowcroft presents a comprehensive survey of the literature on network-layer multipath solutions. More specifically, the paper presents a detailed investigation of two important design issues, namely the control plane problem of how to compute and select the routes, and the data plane problem of how to split the flow on the computed paths. Finally, the paper highlights open issues and possible directions for future work.

In today's wireless networks, routing plays a critical role. The tasks of routing include route selection and packet forwarding. Route selection is about selecting one or more routes connecting a pair of nodes. Packet forwarding makes a one-hop decision on which neighbor should be chosen for forwarding a packet along the selected routes. The highly dynamic and lossy nature of the wireless medium makes routing in wireless networks a challenging problem. In this context, opportunistic routing has recently attracted much attention. It is considered a promising direction for improving the performance of wireless ad hoc and sensor networks. With opportunistic routing, intermediate nodes collaborate on packet forwarding in a localized and consistent manner. Opportunistic routing greatly increases transmission reliability and network throughput by taking advantage of the broadcast nature of the wireless medium. The paper titled "A Survey on Opportunistic Routing in Wireless Communication Networks" by Nessrine Chakchouk presents a comprehensive survey of the existing literature related to opportunistic routing. The paper starts by studying the main design building blocks of opportunistic routing. Then, it provides a taxonomy of opportunistic routing proposals based on their routing objectives as well as the optimization tools and approaches used in the routing design. The paper also reviews the main protocols proposed in the literature for each class. Finally, the paper identifies the major future research directions related to opportunistic routing design, optimization, and deployment.

The primary motivation for computer hacking has shifted away from vandalism and recognition in the hacker community to one of financial gains via malicious attacks and intrusions. It has been reported that today's Internet attacks increasingly aim to exploit individuals and organizations for profit, often resulting in huge financial losses as well as business disruptions around the world. One of the biggest Internet attacks is

the presence of large pools of compromised computers, also known as botnets, sitting in homes, schools, businesses, and governments around the world. Under the control of a single (or a small group of) hacker, botnets are often used to conduct various attacks, ranging from distributed denial-of-service (DDoS) attacks to e-mail spamming, keylogging, click fraud, and spreading new malware. In this context, the paper titled "Botnet in DDoS Attacks: Trends and Challenges" by Nazrul Hoque, Dhruba K Bhattacharyya, and Jugal K. Kalita presents a comprehensive overview of DDoS attacks, their causes, types with a taxonomy and technical details of various attack launching tools. A detailed discussion of several botnet architectures, tools developed using botnet architectures, and their pros and cons are also included. Finally, the paper presents a list of important issues and research challenges.

In the same context of Botnet detection, the paper titled "A Comprehensive Study of Email Spam Botnet Detection" by Wazir Zada Khan, Muhammad Khurram Khan, Fahad T. Bin Muhaya, Muhammad Y. Aalsalem, and Han-Chieh Chao presents a survey, where the paper first discusses the sources and architectures used by the spamming botnets for sending massive amount of email spam. Then, the paper presents detailed chronicles of spamming botnets to systematically describe the timeline of events and notable occurrences in the advancement of these spamming botnets. The paper also offers a comprehensive analysis of detection techniques for email spamming botnet proposed in the literature and categorizes them. Finally, the paper summarizes the future trends and challenges in detecting email spamming botnets.

Internet users concerned about their privacy depend on reliable means to access Internet services anonymously. One way of achieving this is through the use of *anonymity networks*. An anonymity network enables users to access the Web while blocking any tracking or tracing of their identity on the Internet. This type of online anonymity moves Internet traffic through a worldwide network of volunteer servers. Anonymity networks prevent traffic analysis and network surveillance, or at least make it more difficult. In this context, the paper titled "How to Find Hidden Users: A Survey of Attacks on Anonymity Networks" by Esra Erdin, Chris Zachor, and Mehmet Hadi Gunes presents a survey. The paper discusses potential attacks on the anonymity networks that can compromise user identities and communication links. Moreover, the paper summarizes protection mechanisms against such attacks.

Software-defined networking (SDN) is rapidly moving from vision to reality with a host of SDN-enabled devices in development and production. The combinations of separated control and data plane functionality and programmability in the network, which have long been discussed in the research world, have found their commercial application in cloud computing and virtualization technologies. The SDN architecture can be exploited to enhance network security with the provision of a highly reactive security monitoring, analysis and response system. In this context, the paper titled "Security in Software Defined Networks: A Survey" by Ijaz Ahmad, Suneth Namal, Mika Ylianttila, and Andrei Gurtov presents a survey where it starts by analyzing security threats to application, control, and data planes of SDN. The security platforms that secure each of the planes are described followed by various security approaches for network-wide security in SDN. SDN security is analyzed according to security dimensions of the ITU-T recommendation, as well as, by the costs of security solutions. Finally, the paper highlights the future security challenges in SDN, as well as, future directions for secure SDN.

The Internet-of-Things (IoT) is a novel paradigm that is rapidly gaining ground in modern wireless telecommunications. The basic idea of this concept is the pervasive presence of a variety of things or objects, such as radio-frequency identification (RFID) tags, sensors, actuators, and mobile phones, around us, which through unique addressing schemes, are able to interact with each other and cooperate with their neighbors to reach common goals. In this context, the paper titled "Internet of Things: A Survey on Enabling Technologies, Protocols, and Applications" by Ala Al-Fuqaha, Mohsen Guizani, Mehdi Mohammadi, Mohammed Aledhari, and Moussa Ayyash presents a survey on the up to date research efforts in IoT. More specifically, the paper provides an overview of some of the key IoT challenges presented in the recent literature and provides a summary of related research work. Moreover, the paper explores the relation between the IoT and other emerging technologies including big data analytics and cloud and fog computing. Finally, the paper presents detailed service use-cases to illustrate how the different protocols presented in the paper fit together to deliver desired IoT services.

III. Vehicular and Sensor Networks

Vehicular networking technologies can be used to implement a myriad of applications related to vehicles, vehicle traffic, drivers, passengers and pedestrians. Using these technologies, intelligent transportation systems (ITS) aim at streamlining the operation of vehicles, managing vehicle traffic, assisting drivers with safety and other information, along with provisioning of convenience applications for passengers. In this context, the paper titled "Heterogeneous Vehicular Networking: A Survey on Architecture, Challenges, and Solutions" by Kan Zheng, Qiang Zheng, Periklis Chatzimisios, Wei Xiang, and Yiqing Zhou presents a comprehensive survey on recent wireless networks techniques applied to heterogeneous vehicular networks (HetVNETs). The paper starts by outlining the requirements and use cases of safety and nonsafety services. Then, a HetVNET framework is presented that utilizes a variety of wireless networking techniques, followed by the descriptions of various applications for some typical scenarios. After that major challenges and solutions related to both the MAC and network layers in HetVNETs are studied and discussed in detail. Finally, the paper outlines open research issues in HetVNETs.

In the same context of vehicular networks, the paper titled "A Survey on Vehicular Social Networks" by Anna Maria Vegni and Valeria Loscrí presents a survey on the main features of vehicular social networks, from novel emerging technologies to social aspects used for mobile applications, as well as main issues and challenges. In addition, the paper provides an overview of the state-of-the-art on safety and entertainment

applications relying on social networking solutions. Finally, the paper highlights some possible future research directions.

The paper titled "A Data Management Perspective on Vehicular Networks" by Sergio Ilarri, Thierry Delot, and Raquel Trillo-Lado presents a comprehensive survey on data management for vehicular networks. More specifically, the paper describes the technological context of vehicular networks along with the different types of data managed in that environment, and analyzes several challenges. In addition, the paper provides an in-depth coverage of data management for vehicular networks. Finally, the paper outlines some research problems, and extracts conclusions and some lessons learnt.

A vehicular ad hoc network (VANET) is a form of wireless ad hoc network to provide communications among vehicles and nearby roadside equipment. It is emerging as a new technology to integrate the capabilities of new generation wireless networking to vehicles. The paper titled "TDMA-Based MAC Protocols for Vehicular Ad Hoc Networks: A Survey, Qualitative Analysis, and Open Research Issues" by Mohamed Hadded, Paul Muhlethaler, Anis Laouiti, Rachid Zagrouba, and Leila Azouz Saidane presents a novel topology-based classification and an overview of TDMA-based MAC protocols that have been proposed for VANETs. The paper then focuses on the characteristics of these protocols, as well as their benefits and limitations. Finally, the paper offers a qualitative comparison, and discusses some open issues that need to be tackled in future studies in order to improve the performance of TDMA-based MAC protocols for vehicle-to-vehicle (V2V) communication.

The wireless sensor network (WSN) technology can support a broad range of applications such as battlefield surveillance, environmental monitoring, and smart spaces. The coverage problem is a fundamental issue in WSN, which is mainly concerned with the following question: How well a sensor field is observed by the deployed sensors? To optimize network coverage, the traditional approach is to deploy a large amount of stationary sensor nodes and then to schedule their sensing activities in an efficient way. Recently, mobile sensor nodes have received many attentions since network performance can be greatly improved by using just a few of mobile nodes. In this context, the paper titled "Movement-Assisted Sensor Deployment Algorithms: A Survey and Taxonomy" by Mustapha Reda Senouci, Abdelhamid Mellouk, Khalid Asnoune, and Fethi Yazid Bouhidel presents a survey that focuses on a variety of movement-assisted sensor deployment algorithms that have been proposed and studied by researchers and highlights their strengths and limitations. In addition, the paper introduces a taxonomy of movement-assisted sensor deployment algorithms that captures the fundamental differences among existing solutions. Further, comparisons are performed among different algorithms and different classes. Finally, the paper highlights open problems in this area of research.

I hope that you enjoy reading this issue and find the articles useful. Last but not the least, I highly encourage you to submit your work which fit within the scope of ComST. For detailed instructions on the preparation and submissions of articles to ComST, check the URL: http://dl.comsoc.org/livepubs/surveys/. I will be happy to receive your comment and feedback on our journal.

EKRAM HOSSAIN, *Fellow*, *IEEE*
Editor-in-Chief
IEEE Communications Surveys and Tutorials
E-mail: Ekram.Hossain@umanitoba.ca